VISIT…

5

Synthetic Lubricants

Considerable attention has been focused on synthetic lubricants since the introduction into the retail market of synthetic-based or synthesized automotive engine oils. The use of synthetic-based lubricants in aviation and industrial applications extends back over many years. Past interests in synthetic lubricants were due to their ability to resist burning to a greater degree than mineral oils and to provide equipment protection advantages under extremes of operating conditions. These conditions included very low or very high temperatures. More recent interest still entails taking advantage of these performance capabilities, but researchers also want to see how synthetic lubricants may be able to minimize direct or indirect effect on the environment. More details on synthetic lubricants and environmental characteristics are covered in Chapter 6.

The terms ''synthetic'' and ''synthesized'' are both used to describe the base fluids used in these lubricants. A synthesized material is one that is produced by combining or building individual units into a unified entity. The production of synthetic lubricants starts with synthetic base stocks that are often manufactured from petroleum. The base fluids are made by chemically combining (synthesizing) low molecular weight compounds that have adequate viscosity for use as lubricants. Unlike mineral oils, which are a complex mixture of naturally occurring hydrocarbons, synthetic base fluids are man-made and tailored to have a controlled molecular structure with predictable properties.

As developed in Chapter 3, the properties of a mineral lubricating oil result from the selection of crude oil compounds that have the best properties for the intended application. This is accomplished through fractionation, solvent refining, hydrogen processing, solvent dewaxing, and filtration. However, even with extensive treatment, the finished product is a mixture of many compounds. There is no way to select from this mixture only the materials with the best properties, and if there were, the yield would be so low that the process would be uneconomical. Thus, the mineral oils produced have properties that are the average of the mixture, including both the most and the least suited components. This is not to say that lubricants made from mineral-based oils are unsatisfactory. On the contrary, lubricants properly formulated from

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Table 5.1 Synthetic Lubricants Applications and Recommendations

Equipment: lubricated unit	Operating conditions	Advantages of synthetic oils
Industrial		
Calenders—rubber, plastics, board, tile	High temperature	Extended service; reduced deposits, oxidation, and thermal cracking
Paper machines—dryers, calenders, drive gear units	High temperatures, water contamination	Extended service; reduced deposits, oxidation, and thermal cracking
Nuclear power plants—vertical coolant motors, 6000–9000 hp	Annual oil change 8000 hours min	Extended service, fewer deposits
Gas engines	Low temperature start-up	Extended drains, cold temperature starting, fuel economy, lower rates of degradation
Gas turbines	High temperature and low ambients	Extended service, broader temperature application range, fewer deposits
Steam turbines—electro hydraulic control, throttle/ governor	Near-superheated steam lines	Fire resistance
Tenter frame and high temperature conveyor chains	150–260°C (302–500°F)	Reduced deposits and improved wear protection, extended service, less consumption, little or no smoke
Hydraulic systems	−40°C to 93°C (−40°F to 200°F)	Better low temperature pumpability and high temperature stability
Enclosed gears—Parallel, right angle, worm	Moderate to heavy-duty, shock-loaded, severe service	Extended service, better oxidation resistance at elevated temperatures, improved efficiency
Refrigeration compressors—SRM license screw and reciprocating compressors	Severe service	Improved refrigerant solubility, compatibility with HFC refrigerants
Machine tool spindles, freezer plants—motors, conveyors, bearings	High speeds, low temperatures	Extended service, minimized thermal distortion, low temperature start-up
Metal diecasting hydraulic systems	Molten metal, source of ignition	Fire resistance
Mining—continuous miners and associated equipment	Fire hazards exist	Fire resistance
Primary metals—slab, continuous casters, rolling mills, shears, ladles, furnace controls	Fire hazards exist	Fire resistance
Air compressors—reciprocating	Severe service	Extended service, fewer deposits
Air compressors—rotary screw	Severe service	Extended service, fewer deposits
Greased/lubricated bearings	Low to high speeds	Wide temperature service range, longer relubrication intervals

(continued)

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Table 5.1 Continued

Equipment: lubricated unit	Operating conditions	Advantages of synthetic oils
Industrial *(continued)*		
Greased/lubricated bearings *(continued)*	High to very high speeds	Improved low-temperature starting, lower stabilized temperature in service
Grease/lubricated gears	Heavy-duty severe service	Extended service, low temperature starting
Automotive		
Passenger car gasoline engines and front wheel drive manual transmissions	All	Improved fuel economy, low temperature starting, oil economy, wear protection
On- and off-highway gas and diesel engines	All	Improved low-temperature starting and operation, longer drain intervals, fuel and oil economy
Truck and rear wheel drive cars, drive axles: hypoid spiral bevel, and spur gears	All	Improved low-temperature starting and operation, wear protection
Passenger car automatic transmissions—Ford, GM	All	Longer life, improved high and low temperature operation, greatly improved wear protection
Commercial manual transmissions	All	Improved low temperature starting and operation, longer drain intervals, fuel and oil economy
Wheel and clutch bearings	All	Longer relubrication intervals, improved low-temperature starting, reduced leakage vs. oils
Aviation—military and commercial		
Commercial turbine engines—Pratt & Whitney; Allison; GE; SNECMA, Rolls-Royce Avon, IAE, MIL-L-23699D approved	Temperatures to 220°C (428°F)	Wide-temperature service range, high temperature stability
Military turbine engines—MIL-L-7808J approved	Temperatures to 190°C (374°F)	High-temperature stability
Aircraft all—wheel bearings, wing flap-screws—MIL-G-81322D approved	Temperature −55°C to 180°C (−67°F to 351°F)	Wide temperature service range, high, temperature stability
Marine		
High to medium speed marine diesel engines (1.5% sulfur fuel)	Very severe	Improved fuel economy, low temperature starting, oil economy and wear protection, high operating temperature stability

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mineral-based oils will provide good performance in the majority of applications. Synthetics, on the other hand, possess additional performance advantages.

With synthetic lubricant base stocks, on the other hand, the process of combining individual units can be controlled so that a large proportion of the finished base fluid is either one or only a few compounds. Depending on the starting materials and the combining process, the compound (or compounds) can have the properties of the best compounds in a mineral base oil. It can also have unique properties, such as miscibility with water or nonflammability, that are not found in any mineral oil.

In either case, the special properties of the finished synthetic lubricants prepared from the compound may justify the additional cost in applications where mineral oil lubricants do not provide adequate performance. Some of the primary applications for synthetic lubricants are listed in Table 5.1.

The primary performance advantage of synthetic lubricants is the extended service life capability and handling a wider range of application temperatures. Their outstanding flow characteristics at low temperatures and their stability at high temperatures mark the preferred use of these lubricants. Figure 5.1 compares the operating temperature limits of mineral oil and synthetic lubricants. Other advantages, as well as limiting properties, are outlined in Table 5.2.

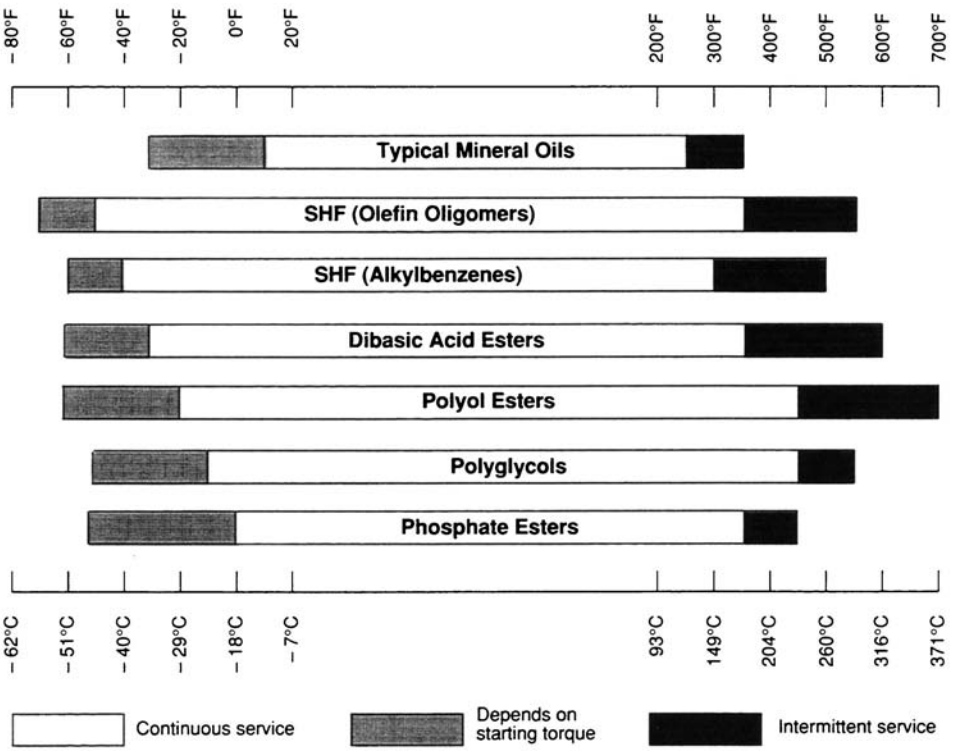

Figure 5.1 Comparative temperature limits of mineral oil and synthetic lubricants.

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Table 5.2 Advantages and Limiting Properties of Synthetic Base Stocks

Synthetic	Advantages vs. mineral oil	Limiting properties
SHF	High temperature stability	Solvency/detergency[a]
	Long life	Seal compatibility[a]
	Low temperature fluidity	
	High viscosity index	
	Improved wear protection	
	Low volatility, oil economy	
	Compatibility with mineral oils and paints	
	No wax	
Organic Esters	High temperature stability	Seal compatibility
	Long life	Mineral oil compatibility
	Low temperature fluidity	Antirust[a]
	Solvency/detergency	Antiwear and extreme pressure[a]
		Hydrolytic stability
		Paint compatibility
Phosphate Esters	Fire resistancy	Seal compatibility
	Lubricating ability	Low viscosity index
		Paint compatibility
		Metal corrosion[a]
		Hydrolytic stability
Polyglycols	Water versatility	Mineral oil compatibility
	High viscosity index	Paint compatibility
	Low temperature fluidity	Oxidation stability[a]
	Antirust	
	No wax	

[a] Limiting property of synthetic base fluids that can be overcome by formulation chemistry.

Various ways have been used to classify synthetic base fluids. Some of these classification approaches neglect similarities between certain types of material, while others may lead to confusion by grouping materials that have similarities in chemical structure but are totally dissimilar from a performance or application standpoint. For the purposes of this discussion, the materials are classified as follows:

Synthesized hydrocarbon fluids (SHFs)
Organic esters
Polyglycols
Phosphate esters
Other synthetic lubricating fluids

The first four classes account for over 90% of the volume of synthetic lubricant bases now used. The fifth class includes a number of materials, some of which are quite costly, that are generally used in somewhat lower volumes in specialized applications. Table 5.3 shows a further breakdown of synthetic lubricant classes and types.

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Table 5.3 Synthetic Lubricants

Class	Type
Synthesized hydrocarbon Fluids	Polyalphaolefins
	Alkylated aromatics
	Polybutenes
	Cycloaliphatics
Organic esters	Dibasic acid ester
	Polyol ester
Polyglycols	Polyalkylene
	Polyoxyaklylene
	Polyethers
	Glycol
	polyglycol esters
	polyalkylene glycol ester
	polyethylene glycol
Phosphate esters (phosphoric acid esters)	Triaryl phosphate ester
	Triakyl phosphate ester
	Mixed alkylaryl phosphate esters
Other	Silicones
	Silicate esters
	Fluorocarbons
	Polyphenyl ethers

I. SYNTHESIZED HYDROCARBON FLUIDS

The SHFs comprise the fastest growing type of synthetic lubricant base stock. They are pure hydrocarbons, manufactured from raw materials derived from crude oil. Three types are used in considerable volume: olefin oligomers, alklated aromatics, and polybutenes. A fourth type, cycloaliphatics, is used in small volumes in specialized applications.

A. Olefin Oligomers (Polyalphaolefins)

Olefin oligomers, also called polyalphaolefins (PAOs), are formed by combining a low molecular weight material, usually ethylene, into a specific olefin. This olefin is oligomerized into a lubricating oil type material, and then hydrogen-stabilized. In this sense, oligomerization is a polymerization process in which a few, usually three to ten, of the basic building block molecules are combined to form the finished material. Therefore, the product may be formed with varying molecular weights and attendant viscosities to meet a broad range of requirements. Polymerization in the usual sense involves condensation of the same basic building blocks (monomers). The structure of a typical olefin oligomer base oil molecule is shown in Figure 5.2.

Olefin oligomers can be considered to be a special type of paraffinic mineral oil, comparable in properties to the best components found in petroleum derived base oils. They have high viscosity indexes (usually $>$ 135 VI), excellent low temperature fluidity, and very low pour points. Their shear stability is excellent, as is their hydrolytic stability. As a result of the saturated nature of the hydrocarbons, both their oxidation and thermal stability are good. Volatility is lower than with comparably viscous mineral

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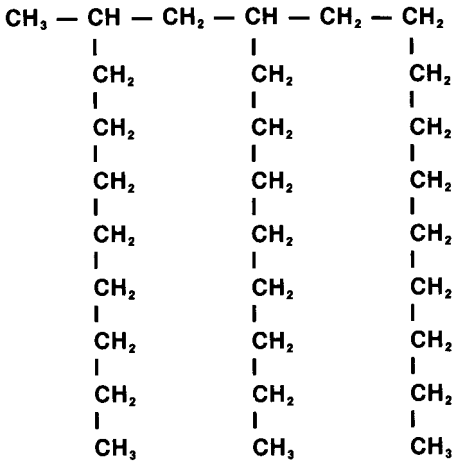

Figure 5.2 Olefin oligomer. This compound, an oligomer of 1-decene, is a low viscosity oil suitable for blending low viscosity engine oils, as well as a variety of other products.

oils; thus, evaporation loss at elevated temperatures is lower. In many applications, it is important that olefin oligomers be similar in composition to mineral oils and that they be compatible with mineral oils, additive systems developed for use in mineral oils, and machines designed to operate on mineral oils. The olefin oligomers do not cause any significant softening or swelling of typical seal materials, which may be a disadvantage when slight swelling of the seals is desirable to keep a system tight and pliable to prevent leakage. However, proper formulation of finished lubricants can overcome this problem.

Olefin oligomers (PAOs) are used widely as automotive and industrial lubricants. They are often combined with one of the organic esters or other synthetic compounds as the base fluid in engine oils, gear oils, circulating oils, and hydraulic fluids.

In industrial applications, olefin oligomers may be combined with an organic ester or other synthetic compounds as the base fluid in high temperature gear and bearing oils and as lubricants for land-based gas turbines or rotary air compressors. SHFs are widely used in gear applications because they possess two unique advantages over mineral oils: lower traction coefficients and higher oxidation stability. Lower traction coefficients translate directly into greater energy efficiency (up to 8%), and their higher oxidation stability enables longer drain intervals. Properly formulated SHF lubricants can yield six to eight times the drain intervals of comparable mineral oils barring any significant contamination of the fluid. They are also formulated as wide temperature range hydraulic fluids, power transmission fluids, and heat transfer fluids. Wide temperature range greases made from an olefin oligomer combined with an inorganic thickener are finding increasing acceptance as long-life rolling element bearing greases for severe duty applications.

In commercial aviation applications, greases formulated from olefin oligomers and inorganic thickener are widely used as general-purpose aircraft greases. These greases are also used for military aircraft applications, as are less flammable hydraulic fluids formulated with olefin oligomer base fluids.

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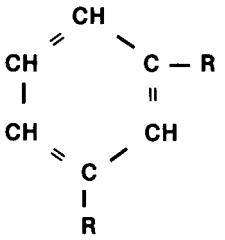

Figure 5.3 Alkylated aromatic. This structure represents dialkylated benzene; R is an alkyl group that usually contains 10–14 carbon atoms for products in the lubricating oil range.

B. Alkylated Aromatics

The alkylation of an aromatic compound, usually benzene or naphthalene, is another widely used method of synthesizing hydrocarbons. The alkylation process involves the joining to the aromatic molecule of substituent alkyl groups. Generally, the alkyl groups used contain from 10 to 14 carbon atoms and are of normal paraffinic configuration. The properties of the final product can be altered by changing the structure and position of the alkyl groups. Dialkylated benzene, a typical alkylated aromatic in the lubricating oil range, is shown in Figure 5.3.

Alkylated aromatics have excellent low temperature fluidity and low pour points, and they exhibit good solubility for additives and degradation materials. Their viscosity indexes are about the same as, or slightly higher than, those of high VI mineral oils. They are less volatile than comparable viscous mineral oils, and more stable to oxidation, high temperatures, and hydrolysis. However, it is more difficult to incorporate inhibitors, and the lubrication properties of specific structures may be poor. As with the olefin oligomers, the alkylated aromatics are compatible with mineral oils and systems designed for mineral oils.

Alkylated aromatics are used as the base fluid in some engine oils, gear oils, hydraulic fluids, and greases in subzero applications. They may be used as the base fluid in power transmission fluids and in gas turbine, air compressor, and refrigeration compressor lubricants. They are also used as additives or supplements in the formulation of some specialty lubricants.

C. Polybutenes

Polybutenes are not always considered in discussions of synthesized lubricant bases, although there are a number of lubricant-related applications for the materials. Polybutenes are produced by controlled polymerization of butenes and isobutene (isobutylene). A typical structure is shown in Figure 5.4. The lower molecular weight materials produced by this process have lubricating properties, while higher molecular weight materials, usually referred to as polyisobutylenes (PIBs), are often used as VI improvers and thickeners.

Polybutenes in the lubricating oil range have viscosity indexes between 70 and 110 and fair lubricating properties; they can be manufactured to have excellent dielectric properties. An important characteristic in a number of applications is that above their decomposition temperature, which is approximately 550°F (288°C), the products decompose completely to gaseous materials.

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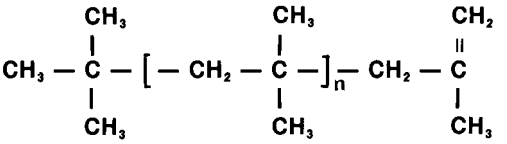

Figure 5.4 Typical molecular structure found in polybutenes. Viscosity is a function of the factor *n,* higher values of *n* giving higher viscosities.

The major use of polybutenes in the lubricant-related field is as electrical insulating oils. They are used as cable oils in high voltage underground cables, as impregnants for insulating paper for cables, as liquid dielectrics, and as impregnants for capacitors. Significant volumes have been used as lubricants for rolling, drawing, and extrusion of aluminum when the aluminum is to be annealed afterward. Other applications include gas compressor lubrication, open gear applications, and as carriers for solid lubricants.

D. Cycloaliphatics

Cycloaliphatics are a class of synthesized hydrocarbons now used in small quantities because of certain special properties they possess. One typical structure is shown in Figure 5.5. Cycloaliphatics are sometimes referred to as traction fluids. Under high stresses they develop a glasslike structure and can transmit shear forces; that is, they have high traction coefficients. At the same time, they perform somewhat of a lubricating function in that they prevent welding and metal transfer from one surface to the other. Their stability is excellent under these conditions.

The main application for the cycloaliphatics at present is in stepless, variable speed drives in which the torque is transmitted from the driving member to the driven member by the resistance to shear of the lubricating fluid. The high traction coefficients of the cycloaliphatics permit higher power ratings than do conventional lubricants.

Also, cycloaliphatics have also found some application in rolling element bearings where speed and load conditions may cause skidding of the rolling elements when conventional lubricants are used.

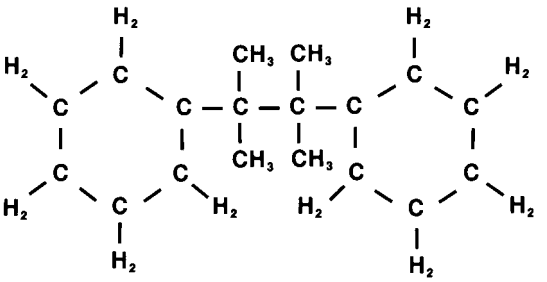

Figure 5.5 Typical cycloaliphatic structure.

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II. ORGANIC ESTERS

Organic esters have been an important class of synthesized base fluids longer than any of the other materials now in use. Their use dates back to World War II, when German chemists used them in mineral oil blends to improve low temperature properties and to supplement scarce supplies of mineral oils. They were first used as aircraft jet engine lubricants in the 1950s and are now used as the base fluid for essentially all aircraft jet engine lubricants. They are also used as the base fluid in many wide temperature range aircraft greases.

Organic esters are oxygen-containing compounds that result from the reaction of an alcohol with an organic acid. The two commonly use classes of organic esters are dibasic acid esters and polyol esters.

A. Dibasic Acid Esters

The various diesters differ in their acid and alcohol components. For all diesters, the acid and alcohol are reacted either thermally or in the presence of a catalyst in an esterification reactor. After the ester has been formed, the water by-product is distilled off and unreacted dibasic acid is neutralized and removed by filtration. The base stock is then suitable for final product blending. As shown in Figure 5.6, the backbone of the structure is formed by the acid, with the alcohol radicals joined to its ends.

Dibasic acid esters exhibit good metal-wetting ability, high film strength, high oxidation and thermal stability, and good shear stability. Diesters will dissolve system deposits and keep metal surfaces clean. This property could be a disadvantage in dirty systems. The hydrolytic stability and antirust properties of diesters are fair. In changing over to diesters from another family of products, care should be taken to assure a thorough cleaning and flushing of the system prior to their installation. Also the compatibility with elastomers and paints used in the system should be reviewed. Diesters are compatible with mineral oils.

Dibasic acid esters have been used as the base fluid for older type I jet engine oils. Generally the use of these oils has been restricted mainly to older military jet engines, and some very limited use in jet engines for industrial service. Diesters are used as the base oils, or components of the base oil, for automotive engine oils and air compressor lubricants. They are also used as the base fluid in some aircraft greases.

These products were developed originally for use as jet engine oils, but now have been replaced, to a large extent, by polyol esters.

B. Polyol Esters

Polyol esters are made by reacting a polyhydric alcohol with a monobasic acid to give the desired ester. In contrast to diesters, as shown in Figure 5.7, in the polyol esters, the

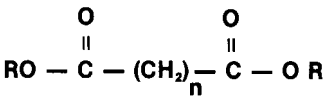

Figure 5.6 Dibasic acid ester: Commonly used acids are adipic ($n = 4$), azelaic ($n = 7$), and sebacic ($n = 8$).

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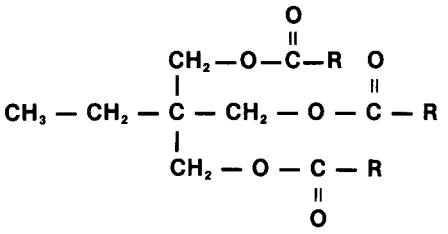

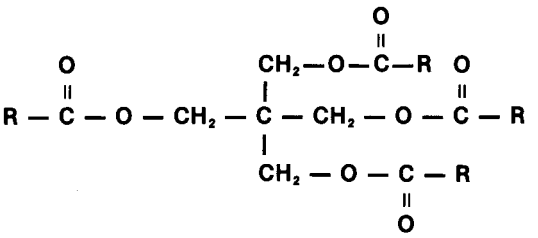

Figure 5.7 Typical polyol esters: acid radicals R typically used contain 6–10 carbons, with those containing an odd number of carbon atoms being generally favored.

polyol forms the backbone of the structure with the acid radical attached to it. As with diesters, the physical properties of polyol esters can be varied by using different polyps or acids. Trimethylol propane and pentaerithritol are two of the polyols that are commonly used. Usually, the acids are obtained from animal or vegetable oils.

Polyol esters have better high temperature stability than diesters. Their low temperature properties and hydrolytic stability are about the same, but their VIs may be lower. Their volatility is equal or lower. The polyol esters also may have more effect on paints and cause more swelling of elastomers.

The primary use of polyol diesters is in type II jet engine oils. They also are used in air compressor oils and as components in some synthesized hydrocarbon blends. More recently, polyol esters have become widely used as refrigeration lubricants, to take advantage of their miscibility with hydrofluorocarbon (HFC) refrigerants. Polyol esters are also the lubricant of choice in refrigeration systems where nonchlorine HFC refrigerants such as R134a are used. They are also used in environmentally sensitive products such as hydraulic fluids and other lubricants for which biodegradable structures are required. Additional information on lubrication of refrigeration compressors can be found in Chapter 17, Compressors.

III. POLYGLYCOLS

Polyglycols cover a wide range of products and properties. Presently, they are the largest single class of synthetic lubricant bases.

Polyglycols are variously described as polyalkylene glycols, polyethers, polyglycol ethers, and polyalkylene glycol ethers. The latter term is the most complete and accurate

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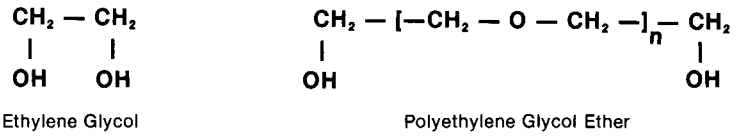

Figure 5.8 Glycols. Ethylene glycol is the simplest glycol; when polymerized, the oxygen bond is formed and it becomes a polyglycol ether.

for the bulk of the materials used in lubricants. Small quantities of simple glycols, such as ethylene and polyethylene glycol, are also used as hydraulic brake fluids. Typical structures for the two types are shown in Figure 5.8.

Polyglycols are polymers made from ethylene oxide (EO), propylene oxide (PO), or their derivatives. The primary raw materials are ethylene or propylene, oxidized to form cyclic ethers (alkylene oxides). Combining ethers derived from ethylene oxide (EO) to propylene oxide (PO) has a profound effect on the solubility of the product in other fluids:

EO:PO = 4:1 Water-soluble, not soluble in hydrocarbons
EO:PO = 1:1 Soluble in cold water, soluble in alcohol and glycol ethers, not soluble in hydrocarbons
EO:PO = 0:1 Not soluble in water, conditionally soluble in hydrocarbons

These comparisons help explain the differences between the various types of, and uses for, polyglycol: automotive antifreeze, brake fluid, water-based hydraulic fluids, hydrocarbon gas compressors, and high temperature bearing lubricants. In addition to ethylene and propylene oxides, butylene oxide is used to provide some polyglycols with specific properties and is oil soluble. Polyglycols made with butylene oxide are more expensive and do not exhibit traction coefficients equal to combinations of EO and PO.

One of the major advantages of polyglycols is that they decompose completely to volatile compounds under high temperature oxidizing conditions. This results in low sludge buildup under moderate to high operating temperatures, or complete decomposition without leaving deposits in certain extremely hot applications. Polyglycols have good viscosity–temperature characteristics, although at low temperatures they tend to become somewhat more viscous than some of the other synthesized bases. Pour points are relatively low. High temperature stability ranges from fair to good and may be improved with additives. Thermal conductivity is high. Not generally compatible with mineral oils or additives developed for use in mineral oils, polyglycols may have considerable effect on paints and finishes. They have low solubility for hydrocarbon gases and some refrigerants. Seal swelling is low, but with the water-soluble types some care must be exercised in seal selection to be sure that the seals are compatible with water. Even if the glycol fluid does not initially contain any water, it has a tendency to absorb moisture from the atmosphere.

The applications for the polyglycols are divided into those for the water-soluble types and those for the water-insoluble types.

The largest volume application of water-soluble polyglycols is in hydraulic brake fluids. Other major applications are in metalworking lubricants, where they can be removed by water flushing or being burned off, and in fire-resistant hydraulic fluids. In the latter application, the polyglycol is mixed with water, which provides the fire resistance. Water-

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soluble polyglycols are also used in the preparation of water-diluted lubricants for rubber bearings and joints.

Water-insoluble polyglycols are used as heat transfer fluids and as the base fluid in industrial hydraulic fluids of certain types, as well as high temperature gear and bearing oils. They are also finding application as lubricants for screw-type refrigeration compressors operating on R12 and hydrocarbon gases, and compressors handling hydrocarbon gases. (The use of R12, a potential ozone layer depleting substance, is being phased out; see Chapter 17 for additional information on refrigeration compressors and refrigerants.) In these latter applications, the low solubility of the gases in the polyglycol minimizes the dilution effect, contributing to better high temperature lubrication.

IV. PHOSPHATE ESTERS

Phosphate esters are one of the other commonly used classes of synthetic base fluids. A typical phosphate ester structure is shown in Figure 5.9.

One of the major features of the phosphate esters is their fire resistance, which is superior to mineral oils. Their lubricating properties are also generally good. The high temperature stability of phosphate esters is only fair, and the decomposition products can be corrosive. Generally, they have poor viscosity–temperature characteristics (low VI), although pour points are reasonably low and volatility is quite low. Phosphate esters have considerable effect on paints and finishes, and they may cause swelling of many seal materials. Their compatibility with mineral oils ranges from poor to good, depending on the ester. Their hydrolytic stability is only fair. They have specific gravities greater than 1, which means that water contamination tends to float rather than settle to the bottom, and pumping losses are higher than is the case with products lower in specific gravity. Their costs are generally high, and they are limited in viscosity.

The major application of phosphate esters is in fire-resistant fluids of various types. Hydraulic fluids for commercial aircraft are phosphate ester based, as are many industrial fire-resistant hydraulic fluids. These latter fluids are used in applications such as the electrohydraulic control systems of steam turbines and industrial hydraulic systems, where hydraulic fluid leakage might contact a source of ignition. In some cases they may also be used in the turbine bearing lubrication system.

Phosphate esters are also used as lubricants for compressors where discharge temperatures are high, to prevent receiver fires and explosions that might occur with conventional lubricants. Some quantities of phosphate esters are also used in greases and mineral oil blends as wear and friction reducing additives.

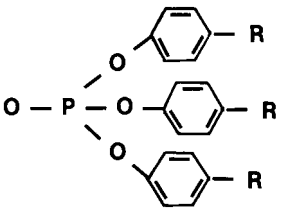

Figure 5.9 Phosphate ester. The R group can be either an aryl or an alkyl type. If, for example, the methyl group (CH_3) is used, the ester is tricresyl phosphate.

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V. OTHER SYNTHETIC LUBRICATING FLUIDS

Brief descriptions and principal applications of some of the other synthetic base fluids are given in Sections V.A–V.D.

A. Silicones

Silicones are among the older types of synthetic fluid. As shown in Figure 5.10, their structure is a polymer type with the carbons in the backbone replaced by silicon.

Silicones have high viscosity indexes, some on the order of 300 or more. Their pour points are low and their low temperature fluidity is good. They are chemically inert, nontoxic, fire resistant, and water repellent, and they have low volatility. Seal swelling is low. Compressibility is considerably higher than for mineral oils. Thermal and oxidation stability of silicones are good up to quite high temperatures. If oxidation does occur, oxidation products include silicon oxides, which can be abrasive. A major disadvantage of the common silicones is that their low surface tension permits extensive spreading on metal surfaces, especially steel. As a result, effective adherent lubricating films are not formed. Unfortunately, the silicones that exhibit this characteristic also show poor response to additives aimed at reducing wear and friction. Some newer silicones show promise of overcoming these deficiencies.

Silicones are used as the base fluid in both wide temperature range and high temperature greases. They are also used in specialty greases designed to lubricate elastomeric materials that would be adversely affected by lubricants of other types. Silicones are also used in specialty hydraulic fluids for such applications as liquid springs and torsion dampers, where their high compressibility and minimal change in viscosity with temperature are beneficial. They are also being used as hydraulic brake fluids and as antifoam agents in lubricants. Some newer silicones are also offered as compressor lubricants.

B. Silicate Esters

Silicate esters have excellent thermal stability and, with proper inhibitors, show good oxidation stability (see Figure 5.11 for their chemical structure). They have excellent viscosity–temperature characteristics, and their pour points are low. Their volatility is low, and they have fair lubricating properties. A major factor for their limited use is their poor resistance to hydrolysis.

Small quantities of silicate esters are used as heat transfer fluids and dielectric coolants. Some specialty hydraulic fluids are formulated with silicate esters.

C. Polyphenyl Ethers

Polyphenyl esters are organic materials that have excellent high temperature properties and outstanding radiation resistance. They are thermally stable to above 800°F (450°C)

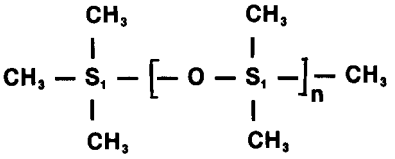

Figure 5.10 Dimethyl polysiloxane, one of the more widely used silicone polymer fluids.

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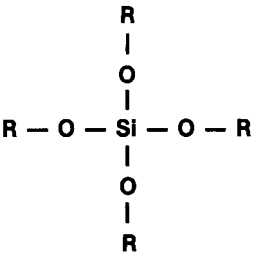

Figure 5.11 Silicate ester: the R groups contain either alkyl or aryl groups. The physical properties are dependent on the nature of these groups.

and have excellent resistance to oxidation at elevated temperatures. High viscosities at normal ambient temperatures, however, tend to restrict their use.

Small quantities of polyphenyl ethers are used as heat transfer fluids, as lubricants for high vacuum pumps, and as the fluid component of radiation-resistant greases.

D. Halogenated Fluids

Chlorine or fluorine or combinations of the two are used to replace part (or all) of the hydrogen in hydrocarbon or other organic structures to form lubricating fluids. Generally, these fluids are chemically inert and essentially nonflammable, often showing excellent resistance to solvents. Some have outstanding thermal and oxidation stability, being completely unreactive even in liquid oxygen. Also, their volatility may be extremely low.

Some of the lower cost halogenated hydrocarbons are used alone or in blends with phosphate esters as fire-resistant hydraulic fluids. Other halogenated fluids are used for such applications as oxygen compressor lubricants, lubricants for vacuum pumps handling corrosive materials, solvent-resistant lubricants, and other lubricant applications entailing highly corrosive or reactive materials.

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